Parallel Simulation Tools for Project-X

with emphasis on

Beam Dynamics Codes of the SciDAC/ComPASS project

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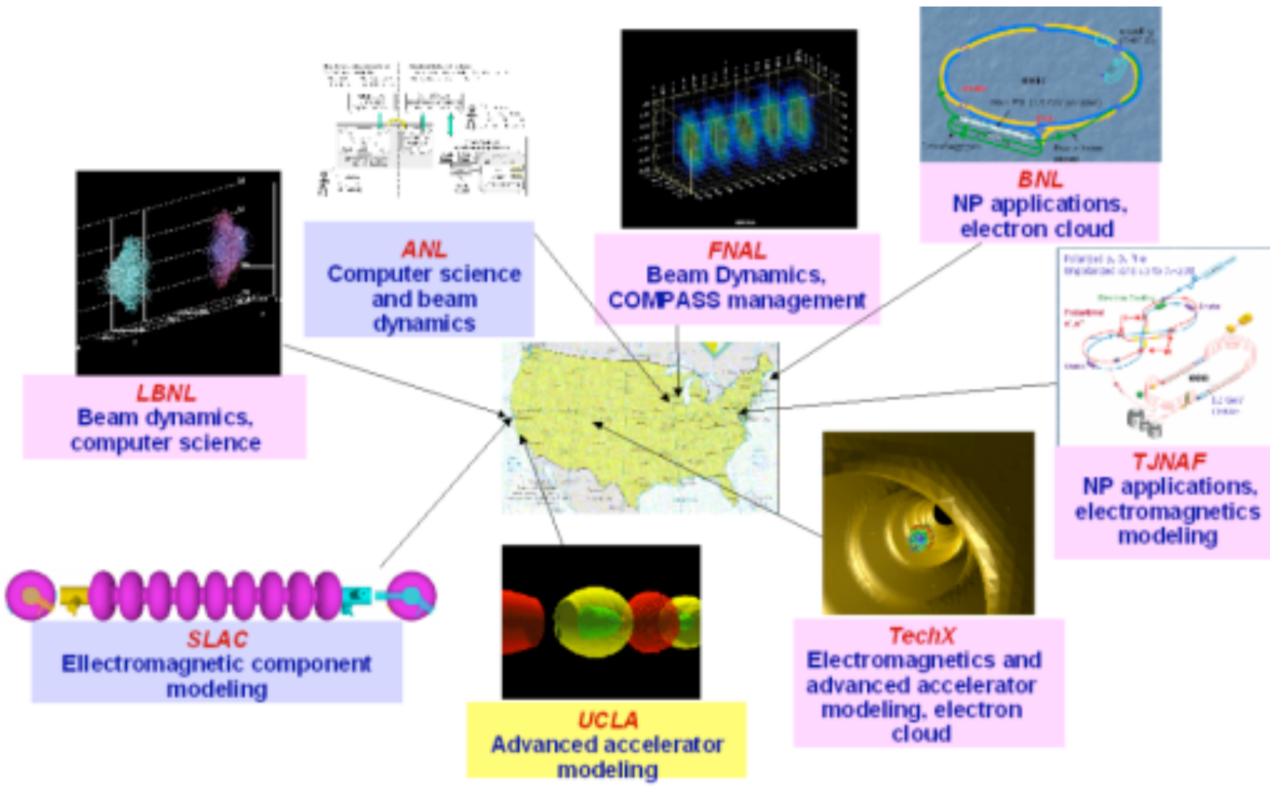
Note:

- This talk will be about parallel beam dynamics codes of the ComPASS project in general, not just codes for rings

The SciDAC ComPASS collaboration

(Community Petascale Project for Accelerator Science & Simulation



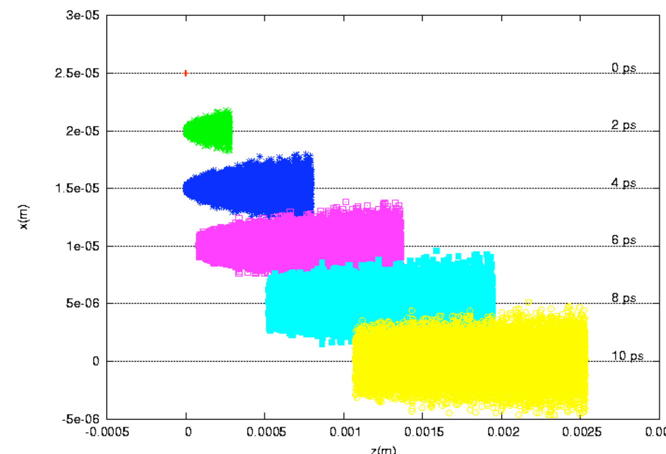
+ many other collaborators in applied math, computer science, and computational accelerator physics

ComPASS Codes & Capabilities

- Beam Dynamics
  - IMPACT, MaryLie/IMPACT, Synergia, WARP/Posinst, QuickPIC, BeamBeam3D
    - Optics, space-charge, wakes, e-cloud,…
- Electromagnetics
  - Omega3p, T3P, S3P, Track3P, VORPAL
    - Large, geometrically complex 3D structures
- Advanced Accelerators
  - OSIRIS, VORPAL, QuickPIC
    - LWFA, PWFA,…

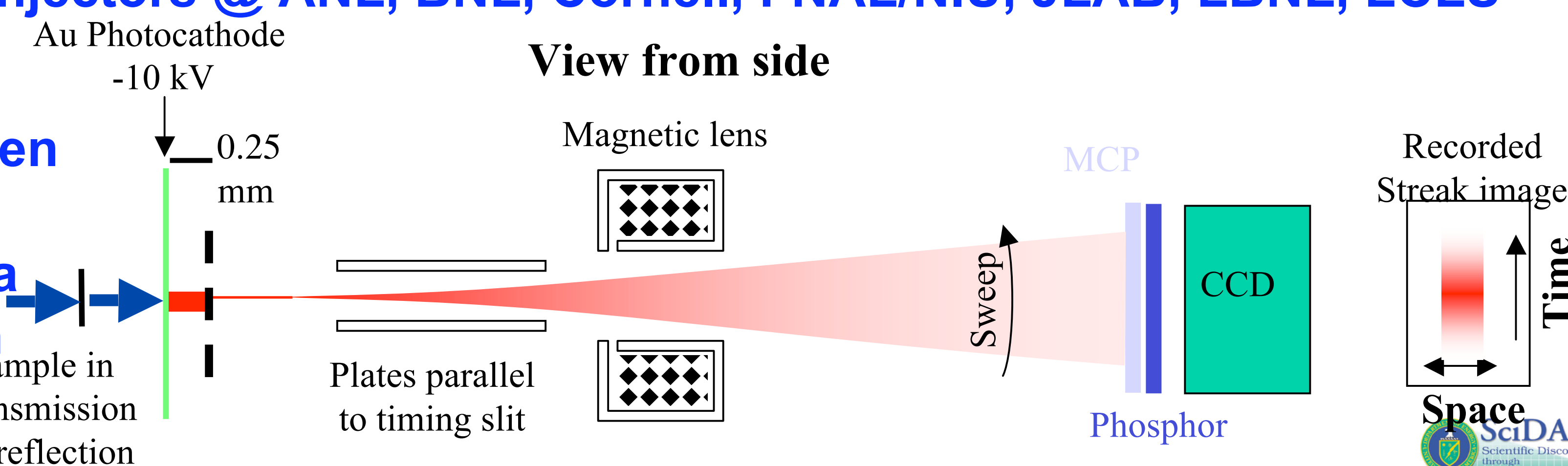
IMPACT: Integrated-Map & Particle Accelerator Tracking

- **Code suite includes IMPACT-Z, IMPACT-T parallel PIC codes**
- **Originally for ion linacs; major enhancements under SciDAC for electron linacs, photoinjectors, …**
- **Recent enhancements**
  - **high aspect ratio Poisson solver**
  - **Multi-grid Poisson solver**
  - **binning for large energy spread**
  - **multi-charge state (RIA)**
  - **wakes, 1D CSR**
- **Applied to SNS, RIA, JPARC, Fermi@Elettra**
- **photoinjectors @ ANL, BNL, Cornell, FNAL/NIU, JLAB, LBNL, LCLS**

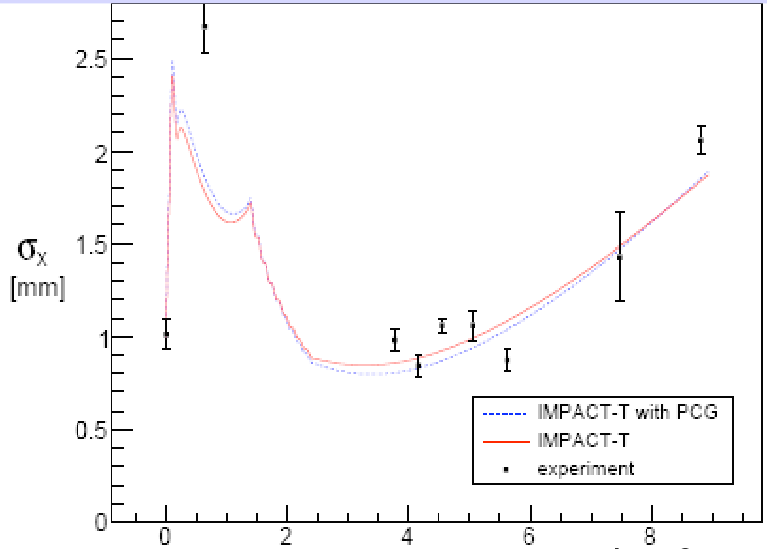


Emission from nano-needle tip

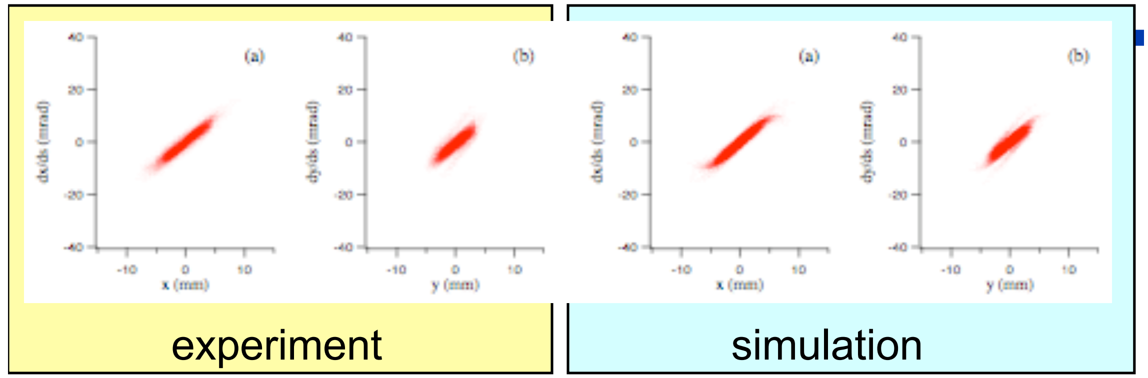
- **Next-gen streak camera design**



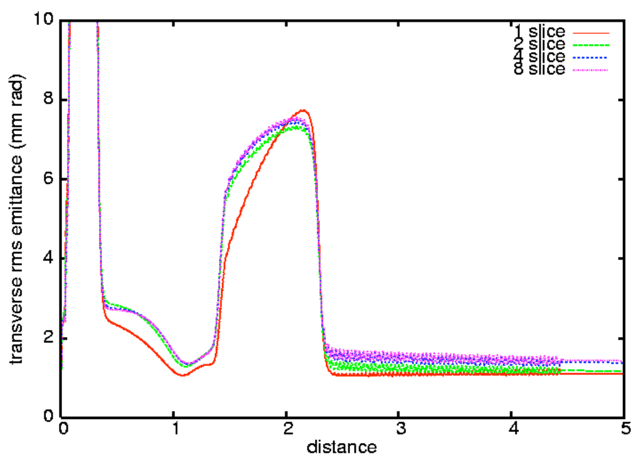
Example applications of IMPACT



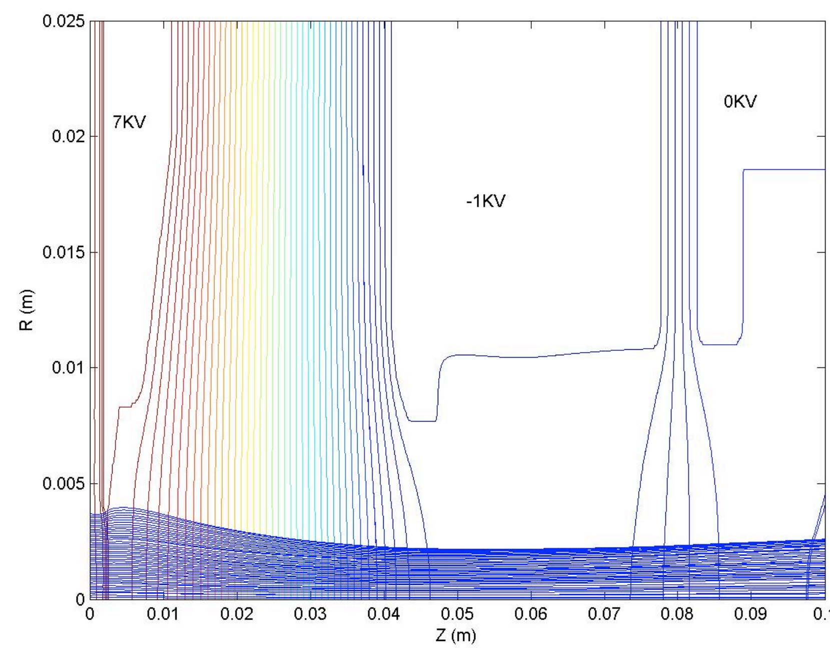
Beam size vs z in the FNAL/NICADD photoinjector: simulation & experiment (C. Bohn/NIU, F. Piot/FNAL)



JPARC commissioning, horizontal phase space, simulation vs. expt (M. Ikegami/KEK)

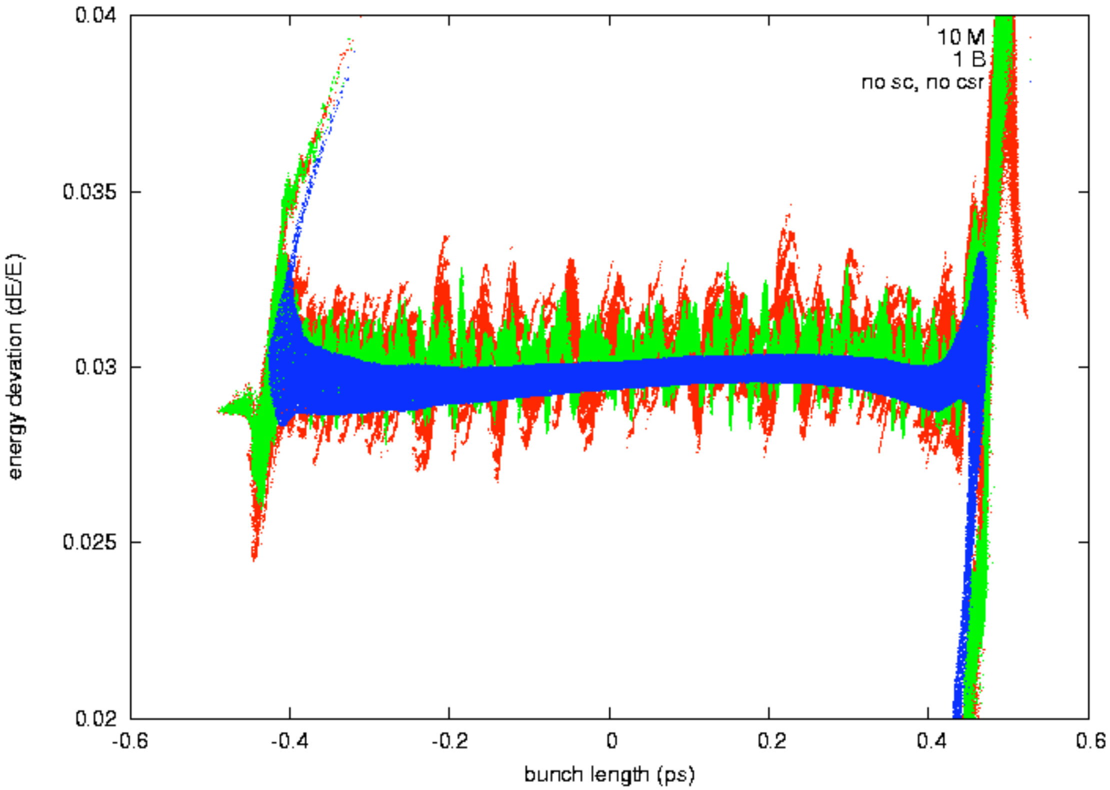


LCLS photoinjector emittance evolution (J. Qiang/LBNL, C. Limbourg/SLAC)

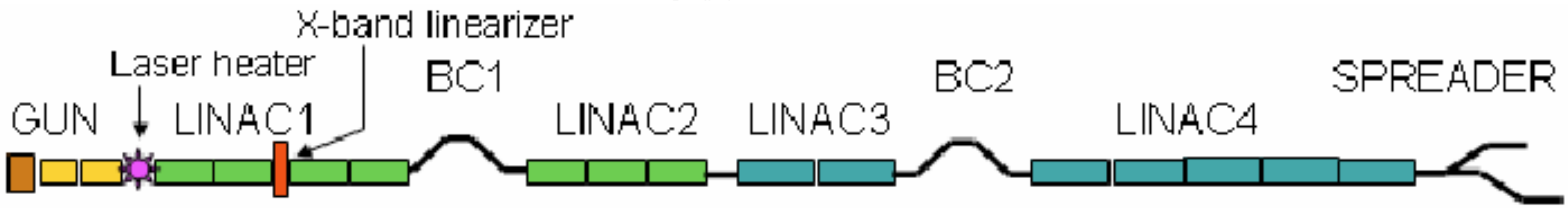


Ion beam formation & transport from RIA ECR ion source (J. Qiang)

IMPACT example: Billion particle simulation of microbunching instability

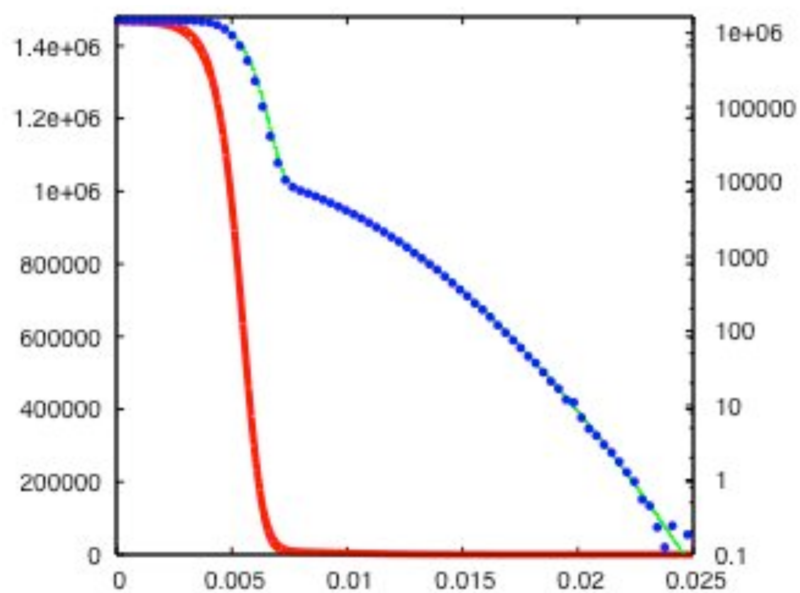


Final Longitudinal Phase Space Distribution Using **10M** and **1B** particles

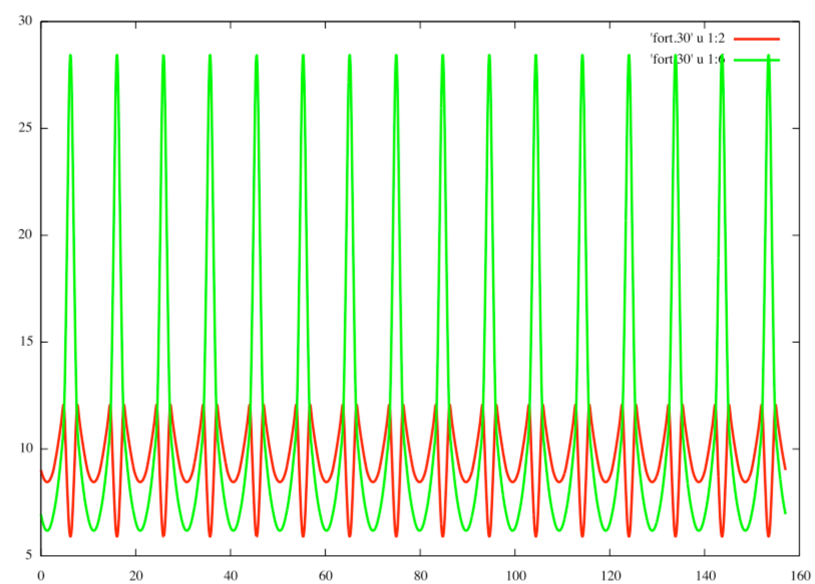


MaryLie/IMPACT (ML/I)

- **Hybrid code combines MaryLie 5th order optics w/ IMPACT parallel PIC**
  - Embeds operating splitting for all thick elements
  - New modules (wakefields, soft-edge magnet models, …)
- **Multiple-physics, multi-purpose**
  - Particle tracking, envelope tracking, map production/analysis
  - Fitting/optimizing, e.g. zeroing 3rd order while minimizing 5th
  - Designing matching sections, e.g. superconducting linacs



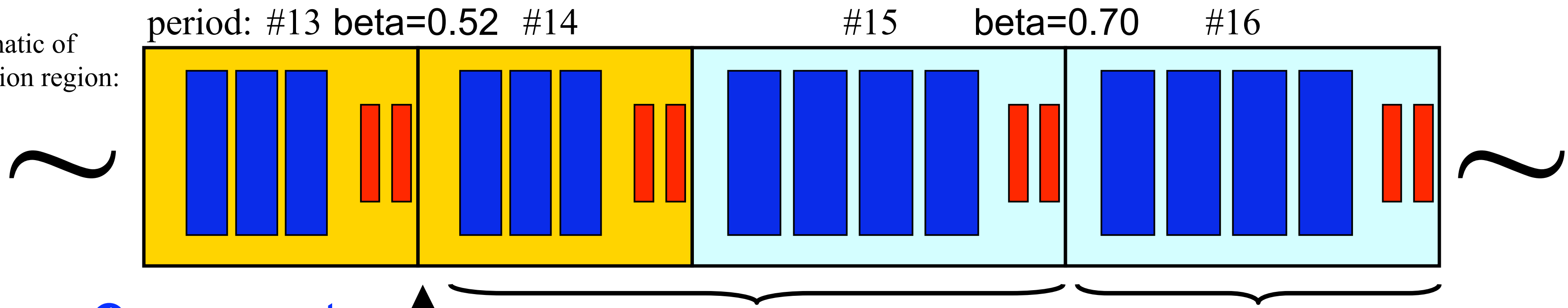
ML/I simulation of bithermal distribution: 95% charge in core, 5% in halo. Note <u>6 order of magnitude</u> resolution in simulated wirescan.



Lattice functions in the PS Booster

ML/I Example: Matching across a transition in a SC linac

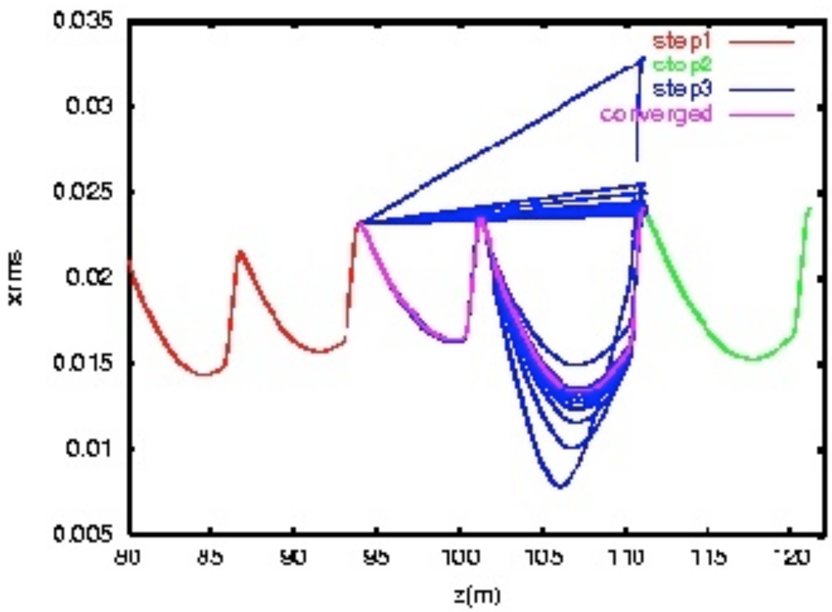
Schematic of transition region:



❶ propagate envelopes to here

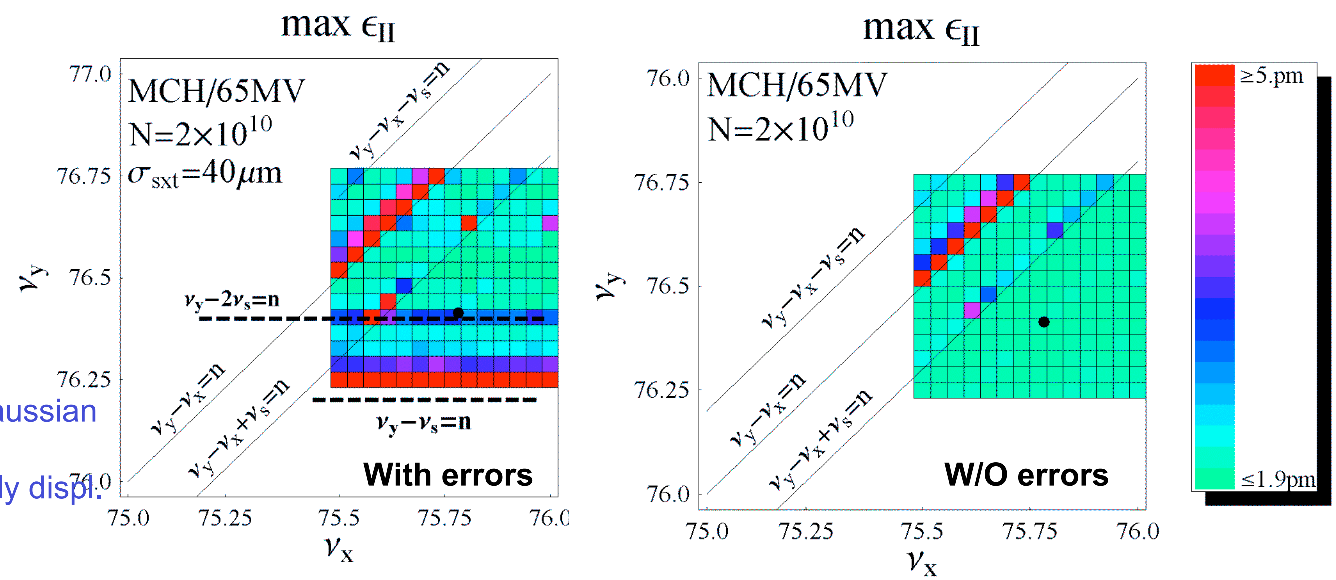
❷ compute matched beam in this period

❸ adjust 4 quad strengths + 3 rf cavity parameters to fit 6 envelope functions (2 each for x,y,z) + E_{final}



Successful 7-parameter match

Fast assessment of space-charge effects in storage rings



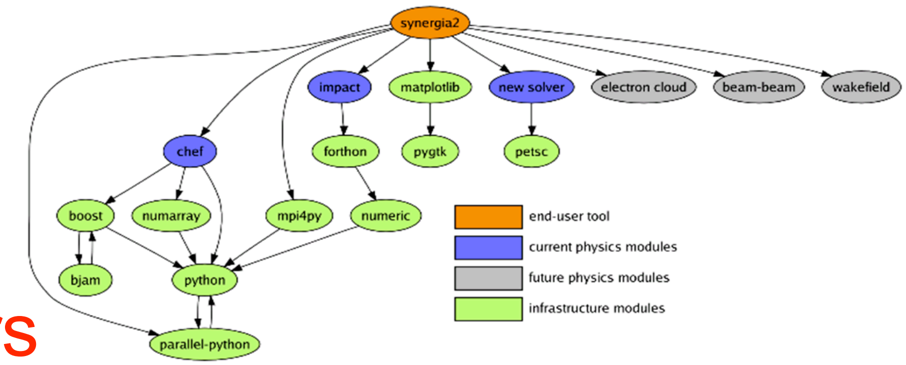
Simulation of max. emittance growth for a proposed ILC-DR Lattice

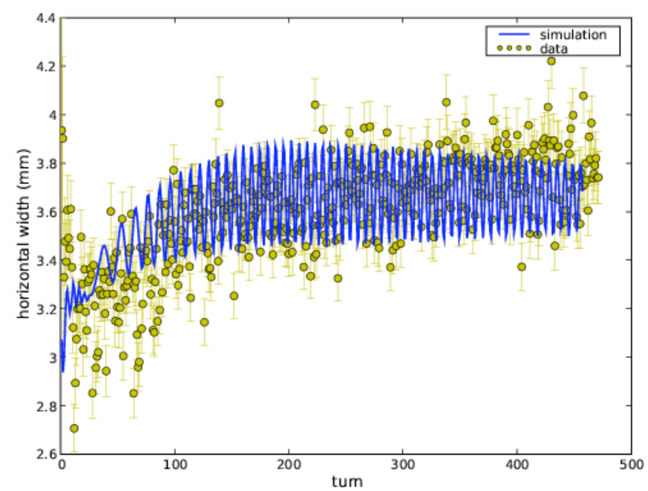
Old dogbone 17 km lattice (TESLA)
Run simul. for ~1 damping time ~= 1000 turns
Initial cond.: equil. beam distrib~=gaussian
SPCH kick: >= once/latt. elem.
"w/erros" means sextupoles vertically displ. randomly w/ sigma=40 microns
Black circular dot= design WP
Color scale in picometers for actual RMS (not norm.) emittance computed from macropartices
#macrop.=500-1000
Max. ε_{II} means vert. eigenemitt. after 1000 turns

- We have developed method for evaluation of space-charge effects in storage rings using a weak-strong (not self-consistent) model.
- Fast evaluation of dynamics can be useful for first assessment of lattice
  - Model implemented in Marylie/Impact (MLI) and applied to study of proposed lattices for the ILC damping rings.

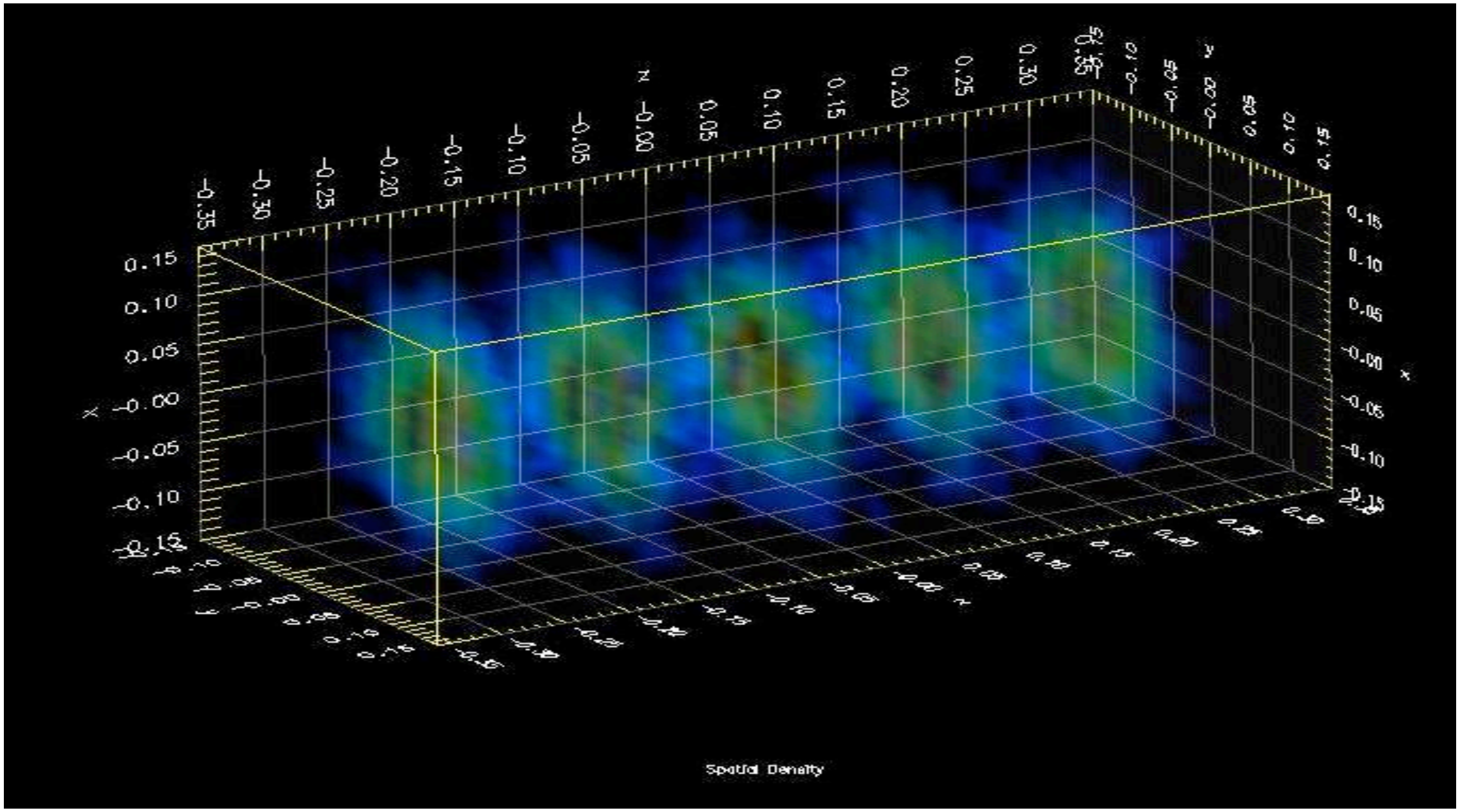
Synergia

- Parallel PIC framework
- 3D space charge
  - variety of Poisson solvers
  - Benchmarked and tested, used in FNAL Booster modeling
- Broad band impedance
- Multi-bunch
- Arbitrary order maps
- MAD and XSIF parsers





FNAL booster modeling using Synergia

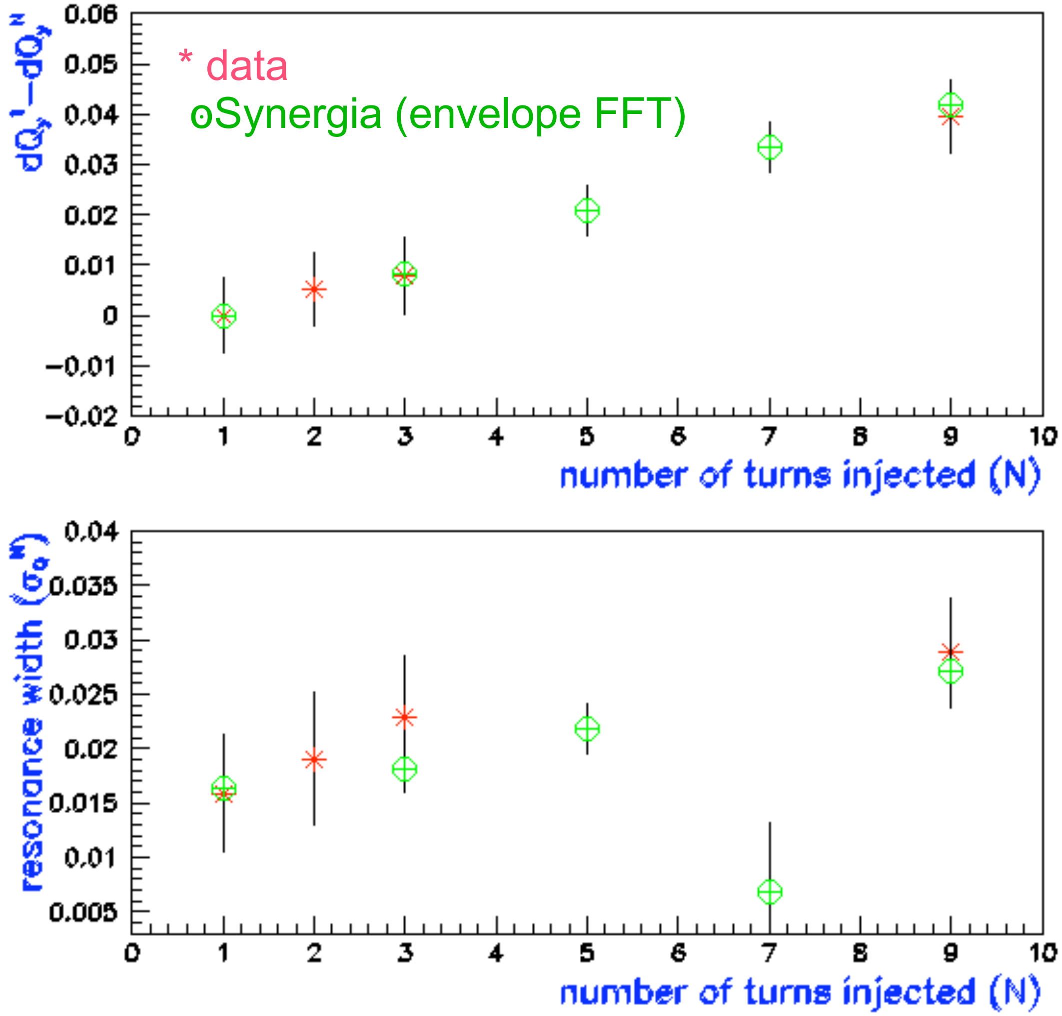


FNAL booster simulation results using Synergia showing the merging of 5 microbunches. SciDAC team members are working closely with experimentalists at the booster to help understand and improve machine performance.
(P. Spentzouris and J. Amundson, FNAL; J. Qiang and R. Ryne, LBNL)

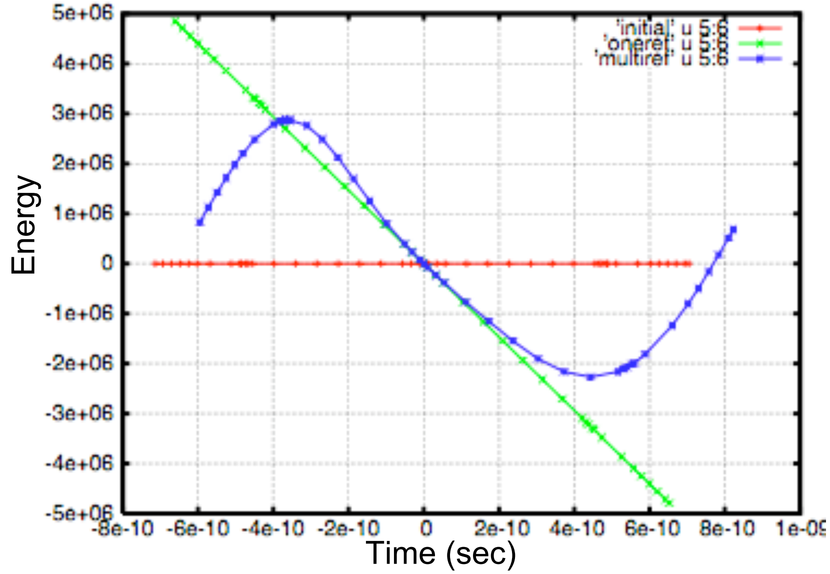
Synergia comparison with expt of space-charge tune shift in Booster

Fit absorption vs tune data and extract apparent location (from quad strength) and width of the half-integer resonance for different currents.

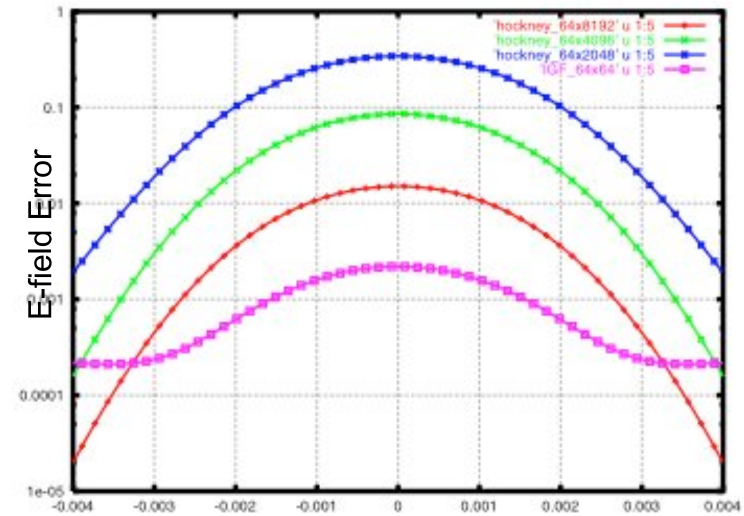
Compare with Synergia: excellent data and simulation agreement



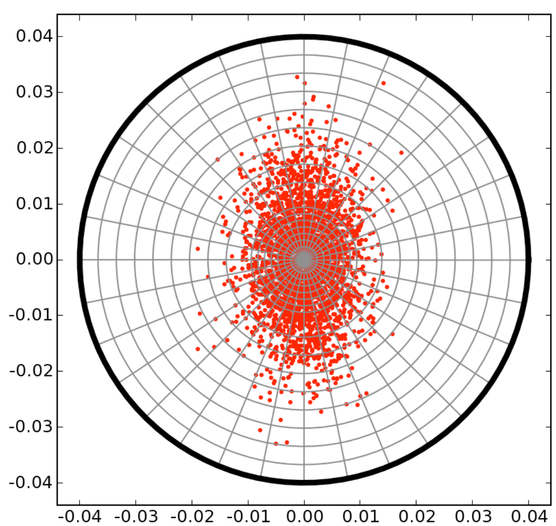
New Methods & Algorithms



RF cavity with multiple reference particles



Simulation of a high-aspect ratio bunch w/ integrated Green Function (IGF) and a conventional algorithm (Hockney). IGF on a 64x64 grid (purple) is more accurate than a standard calculation using 64x2048 (blue), 64x4096 (green), and 64x8192 (red).



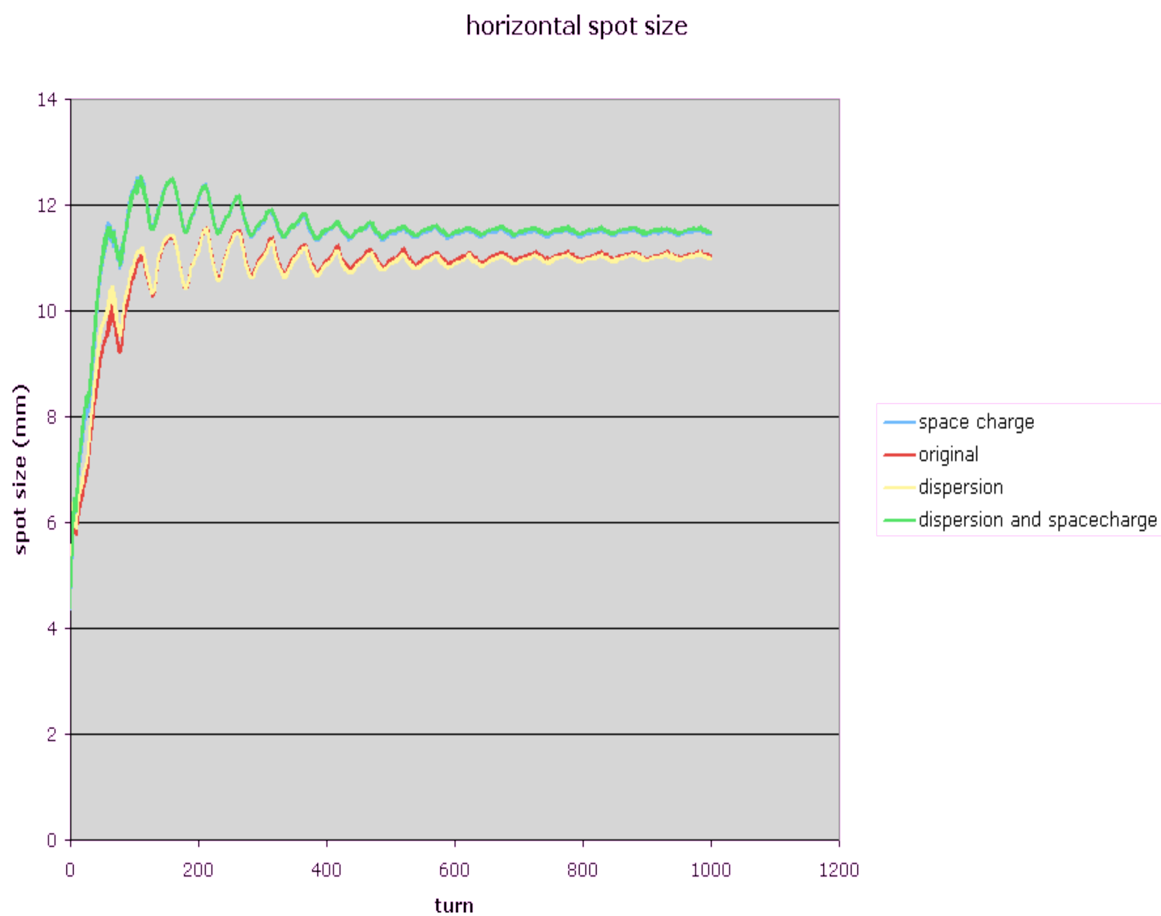
PETSc-based Poisson solver

WARP/POSINST

- [see Miguel Furman's talk]

QuickPIC

- Code developed by Warren Mori's group at UCLA for fast simulation of advanced accelerator concepts
- Modified/enhanced for e-cloud simulations by Tom Katsouleas' group at USC in collaboration with G. Rumolo of CERN



QuickPIC e-cloud modelling in the MI, for p-driver upgrade (3E11 ppb)

Summary

- SciDAC beam dynamics codes provide capability for 3D, multi-physics, large-scale simulations:
  - High order optics (MaryLie, CHEF)
  - Space charge (self-consistent, frozen, multiple b.c.'s)
  - Multiple models of rf cavities and beam dynamics in rf cavities
    - High order maps (D. Abell/Tech-X)
    - Maps from field data or numerical data
  - Collective instabilities (e-cloud,…)
  - Realistic lattices (SIF, XSIF input)
  - Multi-bunch
  - Impedance
  - IBS
  - Transient beam-cavity interactions via circuit model
- Ability to model multiple physical phenomena *simultaneously*
- In some cases simulations w/ real-world # of particles now possible (~few hundred million simulation particles becoming routine)

END OF PRESENTATION